A Comparison of Selected GBN ARQ Schemes for Variable-Error-Rate Channel Using QAM

Petra ALEXOVÁ, Peter KOŠÚT [1], Jaroslav POLEC, Kvetoslava KOTULIAKOVÁ

Faculty of Electrical Eng. and Information Technology
Slovak University of Technology
Ilkovičova 3, 812 19 Bratislava, Slovakia

[1] Accenture, Otto-Volger-Strasse 15, Sulzbach , Germany

Abstract

In non-stationary channels, error rates vary considerably. The paper compares Yao's Adaptive Go-back-N (GBN) Automatic-Repeat-Request (ARQ) scheme with Adaptive go-back-N with sliding window mechanism which both estimate the channel state in a simple manner, and adaptively switch their operation mode. The throughput of these schemes is compared in conditions of Additive White Gauss Noise (AWGN) channel with independent errors using 16-QAM modulation.

Keywords

Channel, model, Automatic-Repeat-Request (ARQ), Quadrature Amplitude Modulation (QAM), AWGN

1. Introduction

ARQ techniques are widely used for error control in data communication systems. Particularly, the GBN ARQ scheme is very popular because it provides higher throughput compared to Stop-and-Wait (SW) ARQ scheme and its implementation is simpler than Selective-Repeat (SR) ARQ scheme since it does not require buffering at the receiver side.

The operation procedure and throughput efficiency of the classic GBN ARQ scheme is well known [1]. The main drawback of this scheme is that, whenever a received block is detected in error, the receiver also rejects the next N-1 received blocks, even though many of them may be error-free. As a result, they must be retransmitted. This causes a waste of transmissions, which can result in worse throughput performance. The larger round trip delay N is involved, the worse throughput is achieved. Sastry modified the classic GBN ARQ scheme [2] by transmitting the block detected as erroneous continuously until a positive acknowledgement (ACK) is received which improves the efficiency when the block error probability P_e is larger than 0.5. Bruneel and Moenaclaey proposed an ARQ schemes [5] that further improves classic GBN efficiency when P_e>0.5. Both improvements of classic GBN ARQ schemes give better results only if the channel stays in a very noisy state. This paper compares two adaptive GBN ARQ scheme for the channel where the error rates changes (P_e varies from as low as approaching zero to as high as 0.5 or above). In these schemes, the transmitter estimates the channel state (low/high error rate) in a simple manner and adaptively changes its operation mode. These two selected adaptive ARQ schemes provide high throughput under a wide range of error rate conditions.

The idea of dynamically changing the ARQ algorithm was previously considered in the technical literature [3], [4], and several schemes were proposed for non-stationary channel applications. The transmitter can estimate the channel state in order to change its operation mode in many manners. The approach taken in [3] assumes knowledge of the instantaneous block error probability, which is difficult to estimate. In this paper, we compare the throughput perfomance of Yao's adaptive GBN scheme and Adaptive GBN with sliding mechanism. Both of these schemes use a simpler method to estimate the channel state.

At the end we compare these schemes in conditions of AWGN channel using 16-QAM.

2. Channel States and ARQ Operation Modes

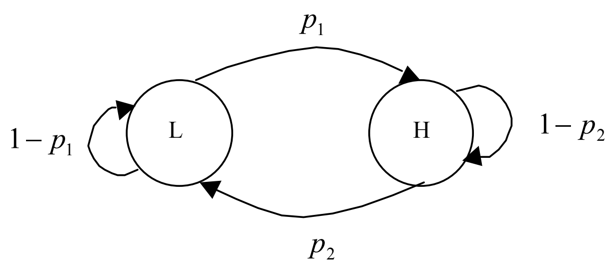

Fig. 1 Channel state model.

In both of the particular schemes, the forward channel (from the transmitter to the receiver) is considered to have two states [4], L state (low error rate) and H state (high error rate), as shown in Fig. 1 (similar as Gilbert model). The channel transits from state L to state H with a probability p_1 and from H to L with a probability p_2. Note that the channel state model shown in the Fig. 1 does not define a channel environment. Instead, it is used by the transmitter to estimate the current channel state. Basically, the channel under consideration in this paper is disturbed by random noise (which results in independent errors) although the error probability P_e may vary considerably from time to time (this assumption is based on monitoring of real radio systems). For simplicity we will assume that there is a noiseless feedback channel, i.e. no errors occur in the acknowledgement messages.

Corresponding to the two channel states, there are two operation modes in the selected GBN ARQ schemes. If the channel is in the L state, the transmitter follows the classic GBN ARQ procedure that throughput can be expressed by [2], [3]

$$\eta_{GBN} = \frac{1-P_e}{1+N.P_e} . \tag{1}$$

Yao makes estimation of channel state by counting contiguous positive acknowledgements (ACK) respectively negative acknowledgements (NAK) [4]. In this operation mode, the transmitter goes back N blocks upon reception of a NAK. If α consecutive NAKs are received the transmitter would consider the channel transiting from L state to H state. The transition probability for Yao's GBN is

$$p_L = P_e^{\alpha} \tag{2}$$

where P_e is block error probability.

Adaptive GBN with sliding window mechanism (SWM) uses a similar process to determinate the channel state. If a NAK is received and α–1 NAKs occurred in last K received acknowledgement messages, the transmitter would consider that the channel is transiting from L state to H state. The transition probability is

$$p_L = C(K-1,\alpha).\left[P_e^{\alpha+1}.(1-P_e)^{(K-1-\alpha)}\right] \tag{3}$$

where

$$C(x,y) = \frac{x!}{y!(x-y)!}$$

and α can be expressed by

$$\alpha = \mathrm{int}(P_{CO}K)+1 .$$

P_{CO} represents block error probability when n-copy ARQ throughput is equal to GBN ARQ throughput. In special cases, it can be expressed by the next formulas

$$P_{CO-2} = \frac{1}{N+1} \quad \text{and} \quad P_{CO-3} = \frac{1+\sqrt{4.N+9}}{2.N+4} \tag{4}$$

where N is round trip delay.

In channel state H, the transmitters of both schemes function in n-copy transmission mode, which operates like the classic GBN ARQ scheme except for sending n copies of a block in each transmission. The throughput of an n-copy ARQ scheme is given in [3]

$$\eta_{n-copy} = \frac{1-P_e^n}{n+N.P_e^n} \tag{5}$$

where n is the number of copies, N is round trip delay and P_e is block error probability.

If using Yao's adaptive GBN, the transmitter would consider that the channel is transiting from state H to state L if β contiguous positive acknowledgments (ACKs) are received. The transition probability is

$$p_H = (1-P_e)^{\beta} . \tag{6}$$

If using GBN with sliding window mechanism, the transmitter would consider that the channel is transiting from H state to L state if last K received acknowledgement messages contain K positive ACKs. The transition probability is

$$p_H = (1-P_e)^{K} \tag{7}$$

where P_e is block error probability and K is the size of examined window.

With the change of channel states (L/H), particular GBN ARQ schemes switch their operation modes (classic GBN and n-copy transmission). The operation mode switching is characterized by a transition matrix

$$T = \begin{bmatrix} 1-p_L & p_L \\ p_H & 1-p_H \end{bmatrix} . \tag{8}$$

The flow charts shown in Fig. 2 and Fig. 3 summarize the two selected ARQ scheme. There are three elements: the GBN transmission block and the n-copy transmission block as defined in [2], [3], and a channel state estimation block.

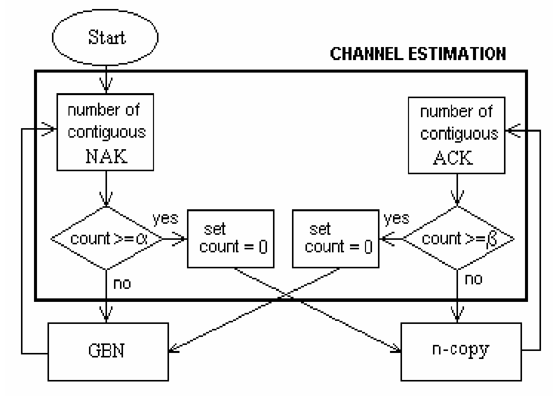

Fig. 2 Yao's adaptive GBN scheme.

Other known channel estimation techniques include signal power measurements [4] and pilot tone transmissions [4]. In the approach with signal power measurements, analog measure of the signal strength is made. The measurements need to be accurate over a wide dynamic signal range that adds estimation complexity [4]. The pilot tone approach, which is often used to assist signal demodulation, can be applied for channel estimation. The pilot tone provides an explicit amplitude/phase reference relating to channel states, which also requires complex signal processing [4]. The method in this paper estimates the channel states without measuring the signal power or other parameters.

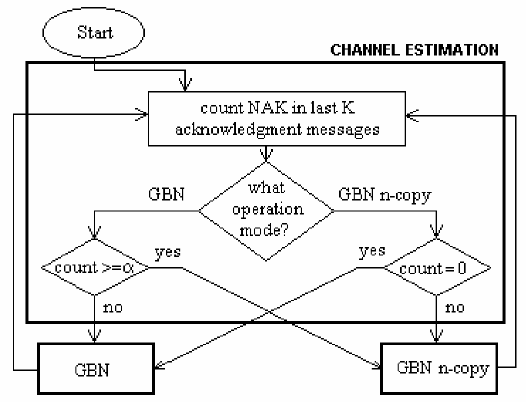

Fig. 3 Adaptive GBN with sliding window mechanism.

3. Simulation and Throughput Analysis

Due to its high spectral efficiency, multilevel quadrature amplitude modulation (M-QAM) is an attractive modulation technique for wireless communication.

The main advantage of multilevel modulation techniques is that it is possible to send the same information sequence through successively less number of signals as symbol size is increased. Put it another way, as symbol size increases, we can send the same information faster since we send less signals. By increasing the symbol size we increase our bit rate by a factor of M. This is why M-ary modulation schemes are attractive.

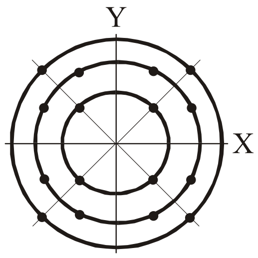

Fig. 4 Constellation pattern of 16-QAM.

Mixed modulations schemes such as QAM which combine PSK and ASK yield constellation diagrams with the points placed on the square lattice such that both amplitude and phase are varying.

The simulation was done with AWGN channel with independent errors using 16-QAM. The packet length was considered to be 512 bits.

The conditional bit error probability for QAM modulation [9]

$$P_b = \frac{2}{k}\left(1 - \frac{1}{\sqrt{M}}\right)\operatorname{erfc}\left(\sqrt{\frac{3}{2(M-1)}k\frac{E_b}{N_0}}\right) \tag{9}$$

where M indicates the number of symbols transmitted, E_b represents energy per bit, N_0 stands for the noise density, and $k=\log_2 M$. The erfc(x) is the error function. In real radio systems P_b varies depending on signal noise ratio.

The described GBN ARQ schemes operate in one of the two ARQ operation modes and switch adaptively between them. The throughput of these schemes can be therefore expressed as an average of the throughput values of the two ARQ operation modes

$$\eta = \eta_{GBN} P_L + \eta_{n-copy} P_H \tag{10}$$

where P_L is the probability that the channel is in L state, and the systems operate in classic GBN mode and P_H corresponds to H state and n-copy mode.

Using matrix (8) we can write two linear equations with two unknowns P_L and P_H

$$\begin{bmatrix} P_L & P_H \end{bmatrix} = \begin{bmatrix} P_L & P_H \end{bmatrix} \begin{bmatrix} 1-p_L & p_L \\ p_H & 1-p_H \end{bmatrix}. \tag{11}$$

Solving the linear equations (11) yields

$$P_L = \frac{p_H}{p_L + p_H} \quad \text{and} \quad P_H = \frac{p_L}{p_L + p_H}. \tag{12}$$

The throughput versus block error probability performance of the selected GBN ARQ schemes are shown in Fig. 5. The performance curves of several comparable ARQ schemes are also shown in the same figure, which includes n-copy ARQ scheme ($n=2$), classic GBN ARQ scheme, Sastry's modification of GBN ARQ scheme, and finally Adaptive go-back-N with sliding observation interval mechanism.

It is shown that the selected schemes outperforms classic GBN ARQ scheme for $P_e > P_{CO}$, and Fig. 5 also indicates that, when $P_e < P_{CO}$, three schemes provide approximately the same performance (classic GBN ARQ scheme, Yao's GBN ARQ scheme, Adaptive GBN with SWM). A drawback of the 2-copy approach is that, compared to the other GBN ARQ schemes, its throughput is very low under low error rate conditions (maximum throughput is $1/n$). Also the performance of Sastry's modification scheme is lower than the performance of the rest schemes, except for the very noisy channel state ($P_e > 0.8$).

The two compared adaptive ARQ schemes have several design parameters. The next figures show how the parameters affect the throughput performance of the compared ARQ schemes.

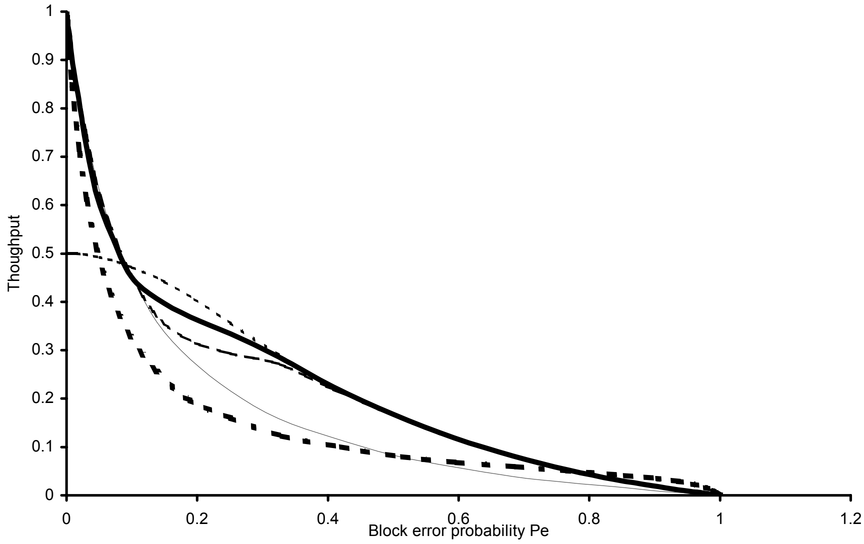

Fig. 5 Throughput versus block error probability for N = 10: solid thin - GBN; dotted thick – Sastry's modifikation of GBN; dashed – Yao's adaptive GBN α = 2, β = 10, n = 2; solid thick– Adaptive GBN with SWM n = 2, K = 10; dotted - n-copy GBN n = 2.

There are three design parameters in Yao's adaptive GBN ARQ scheme - α, β and n - in which, α, β are related to the channel state estimation model. In Fig. 5, we assume α = 2 and β = 10. If α and β remains the same and n is chosen to be 2, 3, and 4 respectively, the Yao's GBN ARQ scheme results in throughput curves as shown in Fig. 6.

It can be seen that although larger n results in better performance of the Yao's GBN ARQ scheme when error rate is higher, the substantial throughput reduction is observed under other error rate conditions.

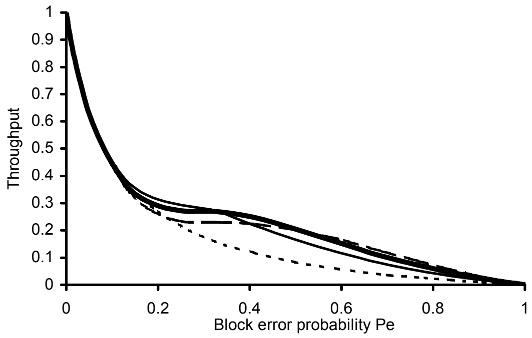

Fig. 6 Throughput versus block error probability. Effects of design parameters on Yao's GBN scheme for N = 10: dotted-classic GBN; dashed - Yao's GBN n = 4; solid thick-Yao's GBN n = 3; solid thin-Yao's GBN n = 2; α = 2 and β = 10.

The effects of Yao's design parameters are further examined in Fig. 7 and Fig. 8. A larger value of α causes higher probability of being in state L (with GBN operations) and, as shown in Fig. 7, yields lower throughput within the error range in which the ARQ operation mode switches. On the contrary, the higher β is chosen, the higher throughput we obtain within the error range in which the ARQ operation mode switches (Fig. 8).

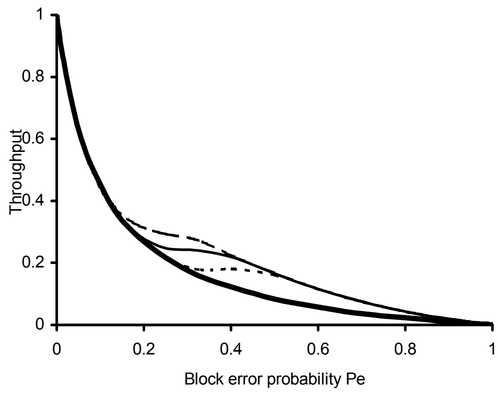

Fig. 7 Throughput versus block error probability. Effects of design parameters on Yao's GBN scheme for N = 10: solid thick-classic GBN; dotted-Yao's GBN α = 5; solid thin-Yao's GBN α = 3; dashed-Yao's GBN α = 2; n=2 and β = 10.

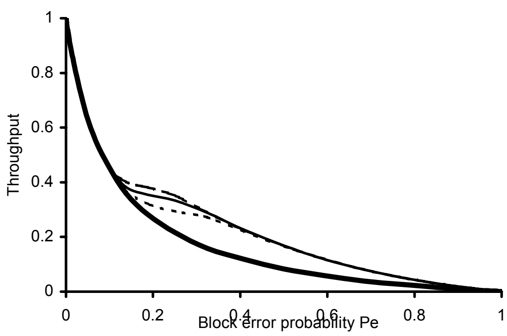

Fig. 8 Throughput versus block error probability. Effects of design parameters on Yao's GBN scheme for N = 10: solid thick-classic GBN; dotted-Yao's GBN β = 10; solid thin-Yao's GBN β = 15; dashed-Yao's GBN β = 20; n=2 and α = 2.

The adaptive GBN with SWM scheme has only parameters - K and n - in which only K is related to channel estimation. The next two figures show the effect of Adaptive GBN with SWM design performance on throughput of the scheme.

The performance of the examined GBN with SWM ARQ scheme not only approaches that of GBN ARQ scheme for low error rates, but also approaches that of *2*-copy ARQ scheme under high error rate conditions (Fig. 5).

In Fig. 9, it can be seen that the larger K is the better performance of the proposed GBN ARQ scheme is achieved within the error range in which the ARQ operation mode switches.

If K remains (K = 10) the same and n is chosen to be 2 and 3 respectively, the Adaptive GBN with SWM ARQ scheme results in throughput curves as shown in Fig. 10.

The results are similar to the throughput performance of Yao's GBN (Fig. 6). Although larger n results in better performance of used scheme when error rate is higher, a throughput reduction is observed under lower error rate conditions, especially within the error range in which operation modes are switched.

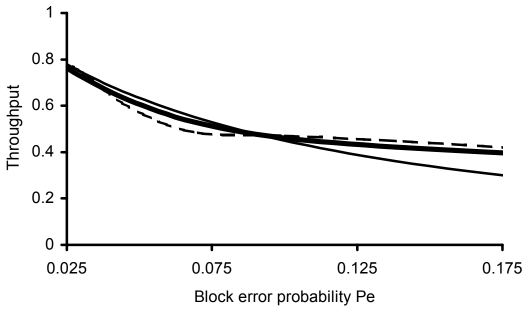

Fig. 9 Throughput versus block error probability. Effects of design parameters on Adapive GBN with SWM scheme for N= 10: solid thin-classic GBN; solid thick-Adaptive GBN with SWM K = 10; dashed-Adaptive GBN with SWM K = 100; n=2.

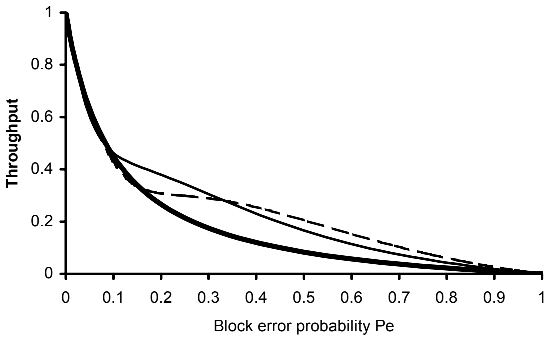

Fig. 10 Throughput versus block error probability. Effects of design parameters on Adapive GBN with SWM scheme for N= 10: solid thick-classic GBN; solid thin-Adaptive GBN with SWM n=2; dashed-Adaptive GBN with SWM n=3; K = 10.

As shown in Fig. 5, the Adaptive GBN ARQ scheme with Sliding Window Mechanism gives better performance than Yao's Adaptive GBN scheme under wide range of error rate conditions. The Adaptive GBN with SWM achieves the throughput performance of classis GBN for low error rates, and the throughput of 2-copy GBN for high error rate. Within the error range in which the ARQ operation mode is switched, the scheme approximates the performance curve of *2*-copy scheme by raising the K value.

4. Conclusion

As discussed in [3], the knowledge of the block error probability is required in order to optimize an ARQ scheme. This paper compared two adaptive GBN ARQ schemes, Adaptive GBN with Sliding Window Mechanism and Yao's adaptive scheme, which simply estimate the channel state (block error probability) based on the acknowledgment messages received and adaptively switch their ARQ operation mode. The adaptive GBN with SWM gives higher throughput performance than Yao's adaptive GBN scheme, under a wide range of error rate conditions. The results were achieved by simulation both of the schemes. The simulation was done in AWGN channel with independent errors using multilevel QAM (M = 16).

As mentioned in [4], the GBN ARQ scheme can be generalized to consider more channel states. For example, three-state channel model with the ARQ scheme consisting of three operation modes, i.e. classic GBN, n-copy, Moeneclaey and Bruneel's scheme [5].

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About authors...

Petra ALEXOVÁ was born in 1980 in Dunajská Streda, Slovak Republic. She received the Bc. degree in information technology from the Faculty of Electrical and Information Technology, Slovak University of Technology. Currently, she is the M.Sc. student of telecommunication engineering at the Slovak University of Technology. Her research interests include Automatic-Repeat-Request (ARQ) and channel modeling.

Peter KOŠÚT was born in 1975 in Detva, Slovak Republic. He received the Engineer and PhD. degrees in telecommunication engineering from the Faculty of Electrical and Information Technology, Slovak University of Technology in 2000 and 2001, respectively. From 2001 he is an expert of corporation Accenture, Sulzbach, Germany. His research interests include Automatic-Repeat-Request (ARQ) and channel modeling.

Jaroslav POLEC was born in 1964 in Trstená, Slovak Republic. He received the Engineer and PhD. Degrees in telecommunication engineering from the Faculty of Electrical and Information Technology, Slovak University of Technology in 1987 and 1994, respectively. From 1997 he is associate professor at the Department of Telecommunications of the Faculty of Electrical and Information Technology, Slovak University of Technology and from 1999 at the Department of Computer Graphics and Image Processing of the Faculty of Mathematics and Physics of Comenius University. He is member of IEEE. His research interests include Automatic-Repeat-Request (ARQ), channel modeling, image coding, interpolation and filtering.

Kvetoslava KOTULIAKOVÁ was born in 1968 in Bohumín, Czech Republic. She received the Engineer degree in telecommunication engineering from the Faculty of Electrical and Information Technology, Slovak University of Technology in 1992. From 1992 she is assistent professor at the Department of Telecommunications of the Faculty of Electrical and Information Technology, Slovak University of Technology. Her research interests include error control, channel modeling and traffic.